Optimal Decision Making in a Dynamic Model of Community Health

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Abstract

This paper presents results from a preliminary system dynamics simulation model of a hypothetical community in poor health and suffering from a "syndemic" of intertwined afflictions. Prevention science has moved from an emphasis on single diseases and epidemics toward a more systemic, ecological perspective, including the concept of causal feedback. From this perspective, afflictions may be seen as being affected by—but also as affecting over time—adverse living conditions and the community's internal capability to address its health and social problems. System dynamics provides a methodology for translating this feedback view into testable form and analyzing its implications, including those involving policy decisions. Our simulation model is relatively compact, containing only three stocks and about 100 variables overall, including some thirty constants that specify fixed aspects of the community, the cluster of afflictions, the effectiveness of problem-fighting efforts, and the cost-effectiveness of potential outside assistance from government and philanthropies. The model is based on the literature and the observations of public health officials, researchers, and community health advocates, but has not yet been verified and refined through case study application. Nonetheless, optimization and sensitivity testing of the model have generated logically defensible hypotheses about the dynamic impacts on community health of various types of outside assistance and their relative benefits. One such hypothesis is that the first priority for outside assistance in communities that are weak and struggling against multiple afflictions should be to assist in building community strength, perhaps even before substantial assistance is provided for direct fighting of prevalent diseases. Another possibility suggested by the model is that outside assistance aimed directly at improving living conditions may have downsides (time lags, unintended side effects) that render such assistance less beneficial in the absence of widespread citizen participation than other types of assistance for health improvement.

1. Introduction

Public health systems around the world are rightly praised for safeguarding human health against an immense array of threats. But can those protections be maintained and more equitably shared in the future? Many observers question what it will take to craft a system of health protection that is capable of controlling contemporary afflictions and emerging hazards, while also creating progressively safer conditions. To be successful in such work, prevention planners must learn more about the causal forces that govern how health problems develop and spread, why they persist, how they interact, and where and among whom they concentrate. Equally important are questions about whose effort is needed in protecting the public's health, and how the relationships among those actors translate into community strength and resiliency. Particular diseases may rise and fall, but the test of a society's public health system lies in the continuing ability of its citizens to minimize their overall burden of affliction and assure the conditions in which people can be healthy.

System dynamics simulation modeling is well equipped for analyzing such complex problems [25]. It can be used to formalize the principles of public health practice, while strengthening the scientific foundation and active policy focus that are the hallmarks of prevention. Part of what makes system dynamics so useful is its emphasis on causal feedback as an organizing principle for explaining observed patterns of behavior [19]. For public health problems, particularly those with

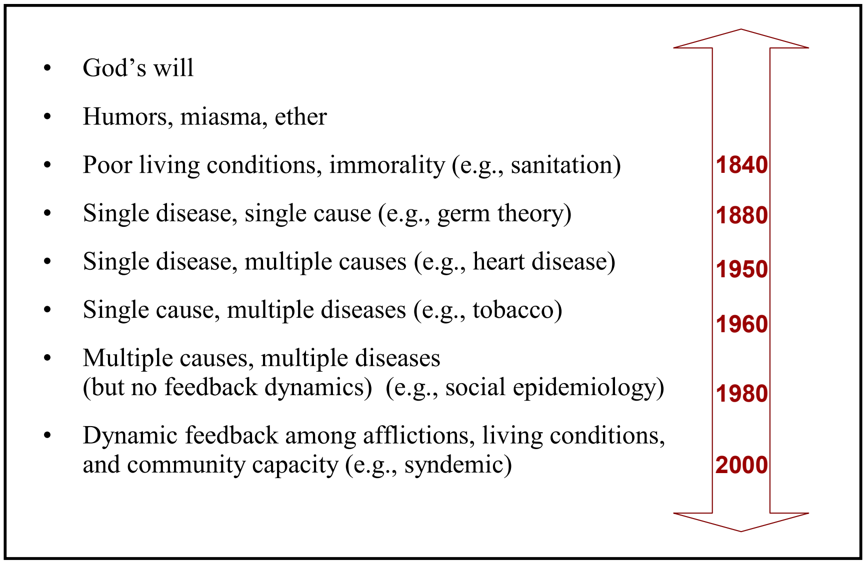

Figure 1. A brief history of theories of poor community health

long delays like chronic diseases, this approach provides a better grasp of forces that are separated in time and space from the health events that individuals experience. In the context of community health, such forces include, for example, the effects of social disparity, changes in living conditions, and investments in community organizing or leadership.

To explain why a particular pattern of affliction develops in a community, it is necessary to look beyond the immediate causes of prevalent diseases. In line with the stated mission and values of public health today, the analytic boundary must widen to include, at a minimum, states of affliction, living conditions, as well as the community's capacity to address them both. This perspective continues a rapid evolution of theories about what causes poor community health, as shown in Figure 1, and moves prevention science from a focus on separate epidemics toward a syndemic orientation [4].

Scholars and practitioners have long observed interactions between health problems, but it was Merrill Singer (an anthropologist studying substance abuse, violence, and AIDS) who first suggested that empirical connections between epidemics might signify the existence of a higher-order phenomenon, which he named a "syndemic" [20, 21, 22, 23]. A related line of thinking can be found in the work that Rodrick and Deborah Wallace have done tracking a "synergism of plagues" within minority neighborhoods in New York City over a 20-year period [29, 30, 31].

The concept of syndemics emerges from an ecological approach to prevention science that began in the 1970s and has gained strength ever since [9, 10]. Today, ecological thinking flourishes as public health professionals craft health promotion policies [26], develop research agendas [27], and move toward a dynamic, ecosocial view of health [17]. Still, there remains a gap within prevention science between the conceptual understanding of health as a dynamic phenomenon and the operational tools that are used to plan and evaluate preventive actions. Most formal models in the field simply have not been made to adhere to the basic properties of ecological systems, but instead still rely on a statistical regression approach unable to capture the causal feedback that makes health problems resistant to change.

By contrast, a system dynamics approach explicitly models causal feedback, and also provides the benefits of simulation for policy planning and evaluation [6, 25]. The remainder of this paper summarizes results from the analysis of a preliminary system dynamics model of syndemics. (See [13] for a previous version of this model.) The objective of this analysis was to better understand the properties and implications of the model, as well as implications regarding optimal interventions for reducing affliction burden in an unhealthy community. Inasmuch as all modeling is iterative [12], these findings represent one step in our formal exploration of syndemics.

2. The Dynamic Model

Our model of syndemics is based on the literature and the observations of public health officials, researchers, and community health advocates with first-hand involvement in efforts to improve population health. It is a general model, meant to be applicable to any community and any cluster of afflictions. The model has

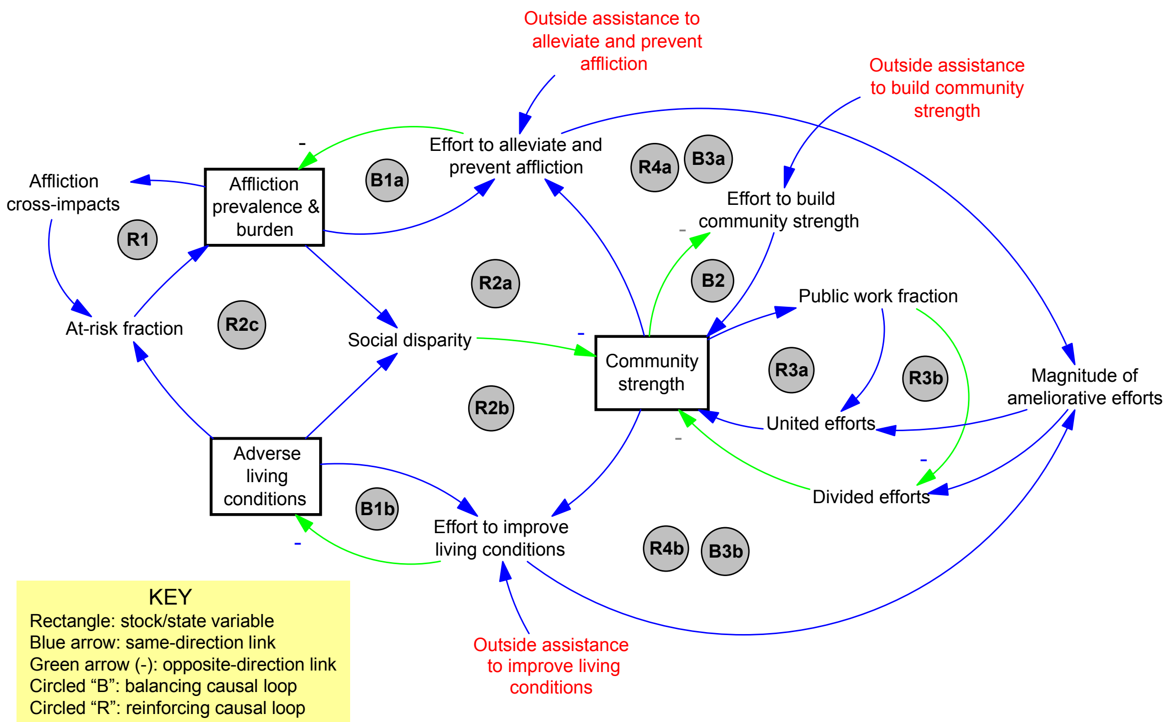

Figure 2. Overview of the community health model

not yet been applied to any particular circumstance, and for this reason should at this point be considered exploratory and suggestive, not a model that is fully tested and determined to be reliable for decision making in specific situations [12, 25]. Although we intend to develop the model further through case studies, it should be noted that even exploratory models can shed valuable new light on a situation. (References [11] and [24], for example, present models that, despite their lack of detailed empirical verification, can simulate recognized dynamics and contain ideas and policy implications that have influenced discussion among scholars.)

An overview of our model's feedback structure is presented in Figure 2. The model contains three stock variables (also known as states, levels, or accumulators), each defined as a fractional measure on a zero to one scale: affliction prevalence, adverse living conditions prevalence, and community strength. Affliction prevalence represents the fraction of the community's population not currently in a state of good physical or mental health.[1] This summary measure [15] is directly related to the average number of unhealthy days per person per month, as defined by the CDC's "Healthy Days" index [2], and which we call affliction burden (after [18]). The mean affliction burden of the 18-and-older population nationwide during the period 1993-2001 ranged from 5.2 to 6.0 days per month. For specified subgroups, the averages for 1993-1997 were: Less than high school education 7.5, Unemployed more than a year 9.1, Heart disease 12.9, Diabetes 15.5, Cancer 19.2 [3].

Figure 2 shows the causal relationships within a community that can drive up affliction, that attempt to control affliction, and that can either undermine or reinforce the ability to control affliction. A syndemic is described in the feedback loop labeled R1 as a vicious cycle in which cross-impacts among afflictions increase the vulnerability of an already afflicted subset of the population to additional poor health. Also contributing to the population's vulnerability in a syndemic are adverse living conditions [32, 33]. In response to unacceptably high levels of affliction and adverse living conditions, the community launches programs to fight these problems, as indicated by balancing loops B1a and B1b, respectively. The magnitude of these responses is related not only to

[1] For the sake of simplicity and transparency, the model presented here does not depict the community's population in any greater detail than in terms of overall affliction prevalence. A previous model [13] considered eight different population stocks, with flows of incidence and recovery for three interacting afflictions. That model also addressed the possible outward migration of non-afflicted individuals in reaction to a high prevalence of affliction in the community.

the severity of the problems, but also to the strength of the community, that is, its internal capacity for action [7, 8].

If community strength is too low to make a strong response to problems, leaders within the community may attempt to build greater strength through organizing and leadership development efforts, as suggested by balancing loop B2. Outside assistance from government and philanthropies may bolster such efforts, as they may also bolster the problem-fighting efforts themselves. But community strength may be hindered by social disparity, a divisive situation made worse by the prevalence of problems among a subset of society that is often feared or distrusted [34]. Because the prevalence of these problems can undermine the community-wide unity needed to fight them, the problems may go unchecked and spread further than they would otherwise; see reinforcing loops R2a, R2b, and R2c.

The loops R3a and R3b indicate how the fighting of problems tends to reinforce a low or high level of community strength [5]. When problems spread in a weak community, problem-fighting efforts tend to be taken over by small groups of professionals who specialize in those problems, a divided process that ends up reinforcing the community's weakness. On the other hand, when problems spread in a strong community, the response tends to be more multi-faceted and elicit greater contributions from ordinary citizens in the form of "public work", a united process that reinforces the community's strength [1, 16].

The remaining loops going through community strength show how the fighting of problems today may affect the community's ability to fight problems in the future. The reinforcing loops R4a and R4b suggest that because united efforts build community strength, they help to make possible more such efforts in the future. The balancing loops B3a and B3b suggest that because divided efforts tend to sap community strength, they may hinder the ability to make more problem-fighting efforts in the future.

The existence of these multiple reinforcing and balancing loops around community strength suggests that the question of how best to provide outside assistance to an afflicted community is not a simple one. Outside assistance for problem fighting provided to a weak community may cause further fragmentation of effort and undermine the community's internal response capability, which could lead to a recurrence of problems after the outside assistance ends. Thus, it may be best in some situations to provide outside assistance that emphasizes the building of strength more than the direct fighting of problems.

The simulation model puts the causal relationships of Figure 2 into testable form. It contains about 100 variables, of which about 30 are parameters used to specify enduring aspects of the situation in regard to affliction vulnerability and contagion, adverse living conditions and community strength, and the effectiveness of programs and outside assistance. After initial tests were done to explore the model's behavior under various parameter settings, a "basic" setting of the parameters was selected which is meant to depict a relatively poor and weak community vulnerable to the high affliction prevalence typical of a syndemic. For example, the basic setting assumes (1) that the community's particular cluster of afflictions includes strong cross-impacts, (2) that the baseline prevalence of adverse living conditions is relatively high, and (3) that the baseline community strength is relatively low.[2]

Figure 3 presents simulation results, depicting the growth of affliction burden over a 20-year period for each of four scenarios. In each scenario, affliction prevalence was initialized (set at Time 0) to a value of 20% that corresponds to an affliction burden of 6, the nationwide average in 2001. One may imagine that this initial condition represents the health status of the population prior to the development of a syndemic, or perhaps describes that portion of the population that is new to the community. Over a period of 20 years, affliction burden under the model's basic setting (the blue line) grows and finally settles at an affliction burden of 10, which is quite high for an entire community.[3] During these 20 years, both the reinforcing and the balancing loops described above are active, but in these scenarios no outside assistance is provided. The result is a pattern of growth that is most rapid initially, reflecting both same-affliction and cross-affliction contagion effects, but then decelerates and converges to a steady-state value. With the increase in affliction comes greater social disparity and, consequently, some erosion in community strength (not shown in Figure 3). Although this erosion does weaken the problem-fighting loops somewhat, the effect is

[2] Parameter values for the basic setting are presented in Table 1. The three parameters of interest here are (1) *Maximum additional at risk fraction from affliction cross impact (MARCI)*, with a basic value of 0.4; (2) *Baseline adverse living conditions prevalence (BALC)*, with a basic value of 0.26; and (3) *Baseline community strength (BCS)*, with a basic value of 0.4. With *MARCI* set to 0.4, the model's steady state at-risk fraction (a fraction of the community's total person-days per month) is 55%. If *MARCI* were set to zero (no cross impacts), the steady state at-risk fraction would be reduced to 41%.

[3] The CDC's Healthy Days survey [3] asks individuals to describe their overall health as excellent, good, fair, or poor, and then to estimate their number of unhealthy days per month. In the 2001 survey, 15% of the 200,000 surveyed described their health as fair or poor, with an average of 15.7 unhealthy days per month, while 85% described their health as excellent or good, with an average of 4.3 unhealthy days per month. The overall average of 6.0 thus disguises a very skewed distribution of unhealthy days. For a community to have an overall average of 10—still assuming that 15.7 represents fair or poor, while 4.3 represents excellent or good—the fraction reporting fair or poor would have to be 50%, much greater than the national average of 15%.

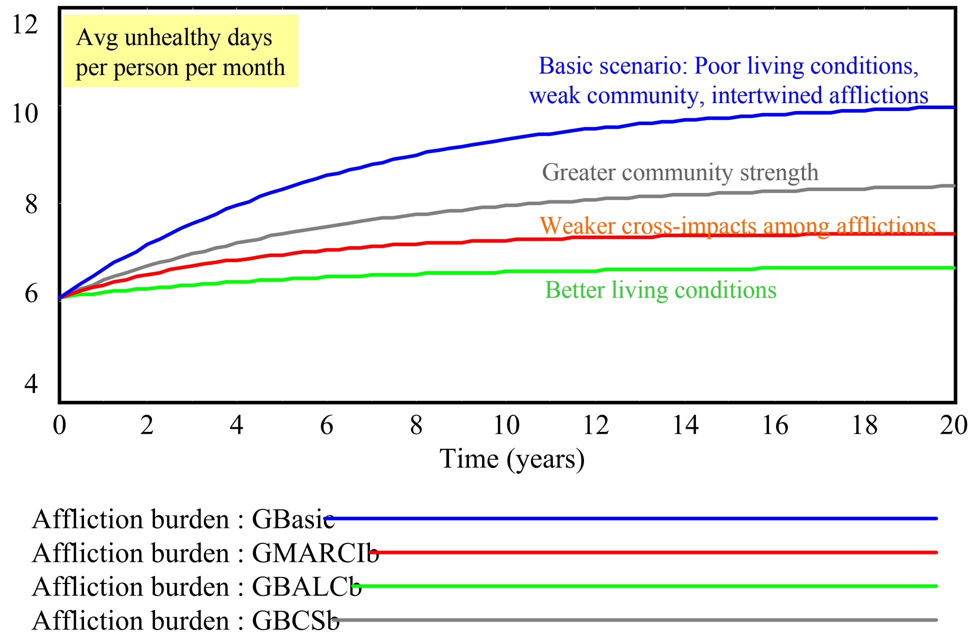

Figure 3. Development of a syndemic—Four scenarios

gradual and does not result in explosive growth in affliction.

In the three other scenarios presented in Figure 3, one or another of the "pessimistic" assumptions of the basic setting is relaxed, and the result is less growth in affliction burden. These are the assumptions described above regarding affliction cross-impacts, baseline adverse living conditions prevalence, and baseline community strength.[4] The results give some indication of how important each assumption is to determining the steady-state level of affliction in the model. The impact of adverse living conditions on vulnerability is perhaps the most important; see the green line. Also quite important is the affliction cross-impact effect; see the red line. Of somewhat less importance in determining steady-state affliction, though still significant, is the effect of community strength on problem fighting; see the gray line. One reason that community strength is not quite as important as the other factors is that some professional efforts to fight individual afflictions can be undertaken, with limited public engagement, even in a weaker community with fewer organizational resources. In particular, it is assumed that only two-thirds of any reduction in community strength translates into reduced capability for fighting afflictions.

3. Optimal Decision Making

The model includes three types of outside assistance—for fighting affliction (AF), eliminating adverse living conditions (LC), and building community strength (CS)—that may supplement the community's own internal efforts in these areas. In the real world, resources for assistance are limited in amount and duration, and decisions must be made about how these resources will be spent. In the model, we have not specified the size of the budget in dollars, but have instead described outside assistance as a total pie of 100% that must be divided among the AF, LC, and CS types. (We assume, for the sake of simplicity, no minimum threshold for spending and no upper limit less than the total available budget for any of the three types of assistance.) Model parameters specify the cost-effectiveness (broadly speaking) of each type of assistance in terms of its per-unit ability to boost program efforts in the community.

[4] In the scenario labeled "Weaker cross-impacts among afflictions", *MARCI* has been changed from its basic value of 0.4 to its better value of 0.1. In the scenario labeled "Better living conditions", *BALC* has been changed from its basic value of 0.26 to its better value of 0.13. In the scenario labeled "Greater community strength", *BCS* has been changed from its basic value of 0.4 to its better value of 0.6. See Table 1 for a complete list of basic, better, and worse values used in sensitivity testing.

- Setting up the decision parameters for optimization

  Define six optimization parameters:

  Fraction of assistance to affliction pgms: T0 (time 0-4), T4 (time 4-8), T8 (time 8-12)
  Fraction of non-affliction assistance to living conditions pgms: T0, T4, T8

  Fraction of assistance to living conditions programs =
  (1 – Fraction of assistance to affliction pgms) x
  Fraction of non-affliction assistance to living conditions pgms

  Fraction of assistance to community building =
  (1 – Fraction of assistance to affliction pgms) x
  (1 – Fraction of non-affliction assistance to living conditions pgms)

- Run the model starting from Time -20, so that it approximates steady state by Time 0

- Vensim® optimizes using a standard grid search algorithm

  MINIMIZE: Affliction burden averaged over Time 4 to Time 20

  SUBJECT TO: $0 \leq$ {Six optimization parameters} ≤ 1

  USING: Modified Powell search, Fractional tolerance = .0003

Figure 4. Set-up and procedure for optimization

The model is set up so that assistance may be provided for a total of 12 years (T0 to T12), and the decision about how to allocate assistance may be made and revised at three specific times: at T0, at T4, and at T8. The ultimate goal of outside assistance for a public health agency such as the CDC is to reduce the burden of affliction in communities while recognizing that the improvement of living conditions and the building of community strength are linked to that goal and part of the agency's responsibility. In terms of the model, one may say that the goal is to minimize the average affliction burden over some period of time, both during the 12 years of assistance and for some time following its termination. (This assistance allocation problem is the subject of an online game version of the model [14].)

With the help of the optimization module of the Vensim® modeling software [28], we have sought to determine what conclusions one may draw from the model about how best to allocate outside assistance. This investigation of optimal decision making started with an analysis of the model at its "basic" parameter setting, but this was only a starting point, and was followed by a wide-ranging sensitivity analysis, as discussed in the next section. Even with the sensitivity analysis, however, it must be emphasized that an exploratory model such as ours is prone to some misspecification, which could affect the results. Any results discussed here must therefore be taken as suggestive rather than prescriptive.

The optimization set-up and procedure is summarized in Figure 4. First, six decision parameters were defined (two parameters each for T0, T4, and T8), fractions that may range from zero to one and that together ensure that the three types of outside assistance always add up to 100%. Next, in order to isolate the impacts of outside assistance and eliminate any transient behavior unrelated to such assistance (such as that seen in Figure 3), all runs are started 20 years prior to T0, ensuring that the model sits at or near steady state at T0. Then, for any given setting of the model's 30-odd other parameters (such as the basic setting), the Vensim® optimizer (employing a standard algorithm, a modified Powell grid search) was used to identify the set of decision parameters that minimizes the "average affliction burden", defined as the simple quarterly average of the affliction burden over an evaluation period that starts at Time 4 and ends at Time 20. As with other aspects of the model, the selection of the evaluation period was guided by our knowledge of public health systems and practices, but should not be taken as the final word on the subject. With the evaluation starting at T4 and ending at T20, and outside assistance ending at T12, the evaluation looks symmetrically at eight years during which assistance is active as well as eight years of the post-assistance period.

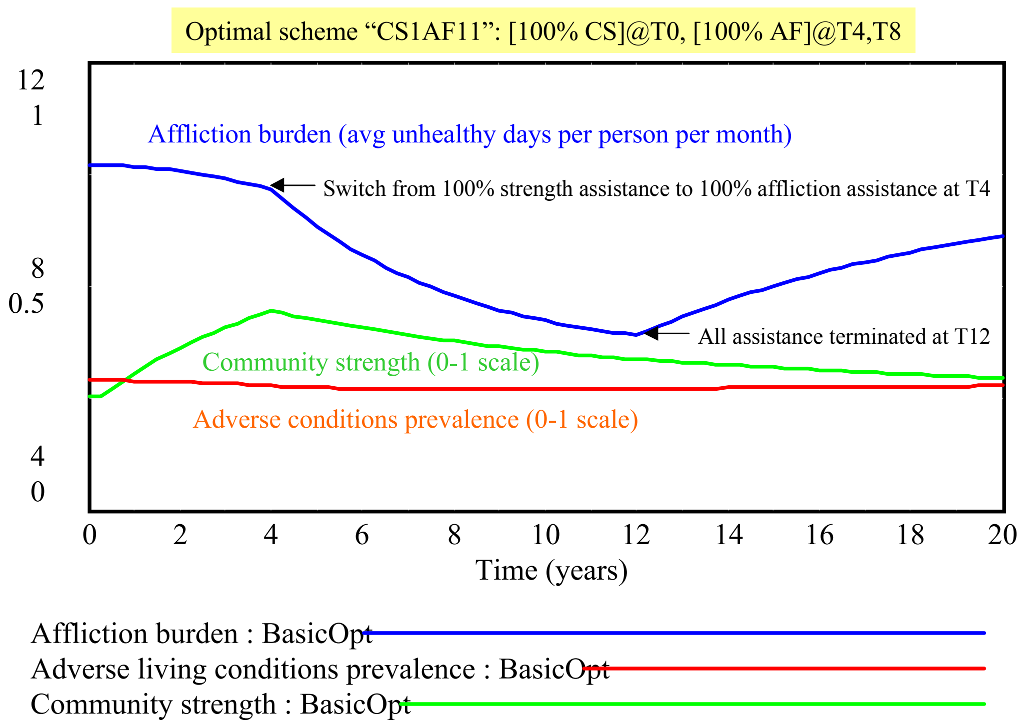

Figure 5. Results under Basic setting with optimal assistance scheme

It is possible that moving the evaluation start time or end time could affect the results of optimization, and we have done some investigation of this possibility, as discussed below.

When the optimization procedure is applied to the basic setting, the result is a scheme which starts with 100% community strength (CS) assistance at T0, then switches to 100% affliction-fighting (AF) assistance thereafter (at T4 and at T8); no assistance to improve living conditions (LC) is provided. We refer to this scheme as "CS1AF11", and its results are presented graphically in Figure 5. The initial CS assistance builds community strength for the first four years, thereby strengthening the community's internal capacity for fighting affliction and adverse living conditions, and ensuring that subsequent problem fighting will be more unified and do less to undermine community strength. The switch to AF assistance at T4 greatly boosts the affliction-fighting programs, and the affliction burden is reduced dramatically over the next eight years. However, after the assistance is terminated at T12, the affliction burden rebounds significantly. The magnitude of this rebound is related to the fact that community strength gradually erodes after the end of CS assistance at T4, so that by T12 the community's internal capacity to fight affliction is not as great as it would have been had the CS assistance continued.

Figure 6 presents a comparison of the optimal CS1AF11 scheme under the basic setting with three other assistance schemes, in terms of their impacts on affliction burden.

- A scheme which involves using only affliction-fighting assistance ("AF111") results in more reduction in affliction initially (through T6) compared with the optimal scheme, but less reduction through T12, followed by a similar rebound in affliction through T20.
- A scheme which involves using only assistance for improving living conditions ("LC111") reduces affliction to a degree nearly identical to the optimal scheme during the first four years, but not nearly as much during the next eight. Though the improved living conditions and reduced affliction burden persist beyond T12 with little rebound, the optimal scheme is still superior to LC111 until T18.
- A scheme which involves using only strength-building assistance ("CS111") has results similar in pattern but uniformly superior to those of LC111 after T4. As in LC111, the improvements persist beyond the termination of assistance at T12 with little rebound, but because the improvements under CS111 are greater than those of LC111, the advantage of the optimal scheme over CS111 is less distinct. In particular, while the affliction burden is higher under CS111 than under the optimal

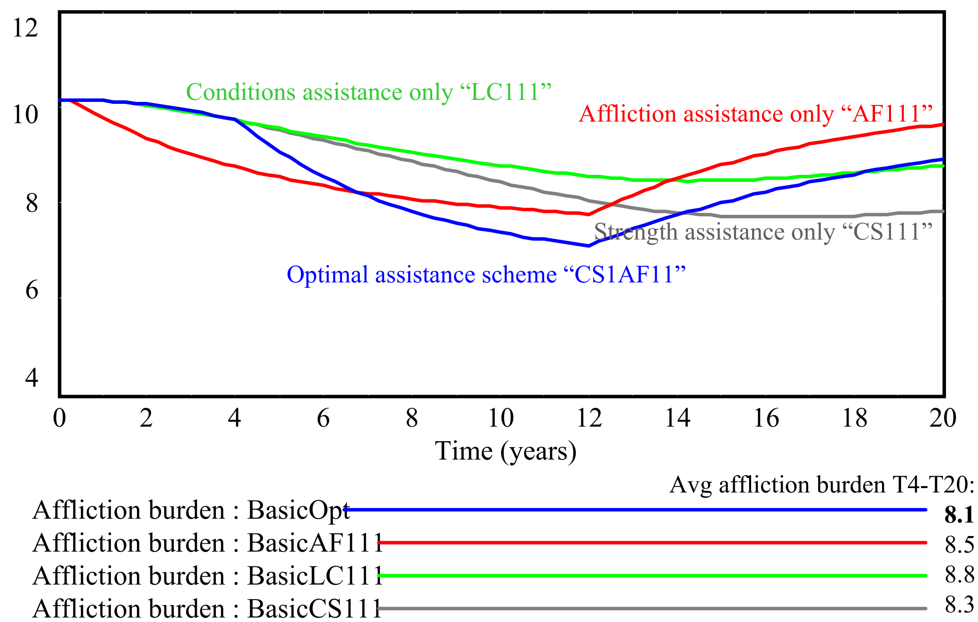

Figure 6. Comparison of affliction burden under basic setting for four different assistance schemes

scheme through T14, it is lower thereafter, increasingly so.

The finding that CS111 is superior to LC111 after T4 may at first seem to contradict the previous finding from Figure 3 that better living conditions do more to reduce the growth of affliction than greater community strength does. But in those alternative growth scenarios we assumed better living conditions or community strength *from the start*, reflecting enduring qualities of the community. In contrast, in Figure 6 the improvement is caused by outside assistance, a process which has some negative side effects. These side effects, acting through the balancing loop labeled B3b in Figure 2, magnify divided efforts rather than public work, thereby undermining community strength to some extent and hindering internal problem-fighting efforts. As a result, LC assistance fails to make as much improvement in living conditions and affliction burden as one might expect based on Figure 3 or the first four years of Figure 6.

The fact there are allocation schemes superior to CS1AF11 early and late in the simulation (AF111 is superior prior to T6, and CS111 is superior after T14) suggests that perhaps the optimal allocation scheme could be different for evaluation periods other than T4 to T20. Further model testing indicates that changing the evaluation start time to T0 does not affect the choice of optimal scheme, but extending the evaluation end time can change the optimal scheme to one that puts more emphasis on CS assistance. If the evaluation end time is extended to something in the range of T21 to T26, the optimal scheme becomes "CS11AF1", with 100% CS assistance at T0 and T4, then AF assistance at T8. If the evaluation end time is T27 or later, the optimal scheme becomes CS111, with 100% CS assistance throughout the 12 year period of assistance. Given a fundamentally weak community, the longer the period of post-assistance evaluation is, the more priority one must give to community strength during the period of assistance, so as to minimize the post-assistance rebound in affliction.

4. Sensitivity Analysis

It is always important to test the sensitivity of model results to parameters that are uncertain, or, in a general model like ours, that may change from one application context to another. In the case of our exploratory syndemic model, most of the parameters fit this description. In particular, the model contains about two dozen parameters that could conceivably change from one case to another, constants describing the community, the cluster of afflictions, the effectiveness of problem-fighting efforts, and the cost-effectiveness of outside assistance.

Table 1 presents a list of the constants that were the subject of sensitivity testing. For each constant, three significantly different values were selected: C_{basic}, C_{better}, and C_{worse}. The basic model setting analyzed in the previous section results when all constants are set to C_{basic}.

Table 1. Alternative parameter settings for sensitivity testing

	Acronym for Runs	Setting Basic	Better	Worse
COMMUNITY & AFFLICTION CHARACTERISTICS				
Baseline adverse living conditions prevalence	BALC	0.33	0.2	0.5
Baseline affliction recovery rate	BAREC	0.1	0.2	0.05
Baseline at risk fraction	BAR	0.2	0.1	0.3
Baseline community strength	BCS	0.42	0.6	0.2
Baseline contagious incidence rate	BCIR	0.6	0.3	0.9
Baseline noncontagious incidence rate	BNIR	0.1	0.05	0.2
Community strength development time	CSDT	4	2	8
Community strength erosion time	CSET	8	12	4
Effect of max professional work on community strength	EMPRO	0.5	0.7	0.3
Effect of max public work on community strength	EMPUB	2	2.5	1.5
Effect of max social disparity on community strength	EMDIS	0.5	0.7	0.3
Living conditions erosion time	LCET	8	12	4
Living conditions improvement time	LCIT	4	2	8
Maximum additional at risk fraction from affliction cross impact	MARCI	0.4	0.1	0.7
Maximum additional at risk fraction from living conditions	MARALC	0.75	0.5	1
PROGRAMS & OUTSIDE ASSISTANCE				
Effect of max programs on adverse conditions	EMPALC	0.5	0.3	0.7
Effect of max programs on affliction incidence	EMPAI	0.6	0.4	0.8
Effect of max programs on affliction recovery	EMPAR	2	2.5	1.5
Internal capacity for affliction pgms if no community strength	ICAP0	0.33	0.5	0.2
Internal capacity for LC pgms if no community strength	ICLCP0	0	0.25	NA
Max boost in affliction programs from assistance	MBAPA	0.3	0.5	0.2
Max boost in community strength from assistance	MBCSA	0.3	0.5	0.2
Max boost in living conditions programs from assistance	MBLCPA	0.5	0.7	0.3

Other settings tested included:

- All settings in which a single constant is changed to C_{better} and all others left at C_{basic}
- All settings in which a single constant is changed to C_{worse} and all others left at C_{basic}
- Several other "combination" settings in which two to five related constants are changed to C_{better} or C_{worse} and all others left at C_{basic}. For example, one might combine a lower Baseline at risk fraction (BAR) and a lower Maximum additional at risk fraction from affliction cross impact (MARCI) to create a scenario in which the community's vulnerability to affliction is reduced. Or, one might combine a greater Effect of max programs on affliction incidence (EMPAI) and a greater Effect of max programs on affliction recovery (EMPAR) to create a setting in which affliction-fighting programs are more effective than they are in the basic setting. Or, one might combine all four of these parameter changes to create a setting with lower affliction vulnerability combined with more effective affliction-fighting programs.

For each setting, the optimization procedure described in Figure 4 was performed. For most of the over fifty settings tested, the optimal assistance allocation scheme turned out to be the same as under the basic setting, namely CS1AF11. But for twelve of the settings (six of them involving change in a single constant, the other six involving combination changes), the optimal assistance scheme is something different than CS1AF11. In five of these cases, CS1AF11 does nearly as well as the optimal scheme, with CS1AF11 producing an average affliction burden greater than that of the optimal scheme by no more than 0.1 unhealthy day per person per month. In the other seven settings, where CS1AF11 is neither optimal nor very close to optimal, the specific parameters that have been changed from the basic setting are relatively few in number and type. These include:

- Parameters modulating the direct impact or effectiveness of problem-fighting efforts (EMPAR and EMPAI for affliction, EMPALC for living conditions), and
- Parameters modulating the boost that assistance gives to the magnitude of effort—or, as we have said, the cost-effectiveness of assistance (MBAPA for affliction, MBLCPA for living conditions, and MBCSA for community strength.)

A final observation from the sensitivity testing is that living conditions (LC) assistance is part of the optimal scheme for only a small number of settings. Moreover, only under two of these settings does an optimal scheme including LC assistance significantly impact the average affliction burden relative to CS1AF11, which includes no LC assistance. Both of these settings assume greater effectiveness of LC efforts, as well as greater cost-effectiveness of LC assistance.

5. Conclusion

Scholarly research in public health has started to recognize the systemic and circular nature of entrenched community health problems, gradually advancing from an epidemiological to a syndemic orientation. The question now is how to use a syndemic perspective for the development of practical guidelines for action. Simulation modeling is a methodology well suited to analyzing problems marked by feedback dynamics, to help in the development of such guidelines. The model presented in this paper represents an initial attempt to translate current thinking on syndemics into the testable form of a simulation model, and to determine how such a model might inform community health policy decisions.

Our model is at this point an exploratory one, not yet verified and refined through case study application. Nonetheless, testing and optimization of the model have led to several hypotheses about the dynamic impacts of various types of outside assistance on community health. One such hypothesis, familiar to experienced practitioners, is that the first priority of philanthropies and government in addressing communities that are weak and struggling against multiple afflictions should be to assist in building community strength, enabling a greater degree of citizen-led public work, perhaps even before substantial assistance is provided for direct fighting of prevalent diseases. Another hypothesis suggested by the model is that outside assistance aimed directly at improving living conditions may often be insufficiently cost-effective, due to time lags and unintended side effects, to warrant making such assistance a high priority in the absence of widespread citizen participation—this despite the fact that adverse living conditions are a powerful determinant of vulnerability to affliction.

The value of a simulation model lies not only in the identification of hypotheses for optimal decision making, but also in the ability it provides to explain how those hypotheses emerge logically from a feedback structure that integrates the best available knowledge on the subject. The hypotheses described in the previous paragraph, for example, reflect the presence in the model of relationships depicting the perverse effect that problem-fighting programs may have on community strength when the community is not strong to begin with. We intend to continue moving the model in a direction that will enable it to be useful and transparent in this way to other investigators in the area of community health.

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